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Electric-Arc Temperature Measurements

PAUL W. SCHREIBER, Thermomechanics Research Laboratory, (ARN) ARL

Electric arcs present a challenge to the theorist and the experimental physicist. Although the analysis of electric-arc phenomena lies in the realm of well-developed physical theories, the determination of the dominant processes which are responsible for arc behavior and the energy exchange with its surroundings requires a keen insight into many areas of physics. Often this insight cannot be brought to fruition because basic cross-section information and transport properties are not known. Although gross energy losses can provide experimental checks on analytical solutions, the temperature dependence of transport properties makes it imperative to measure the temperature distribution in research arcs if progress in arc technology is to continue.

Temperature distributions have been measured for a number of arcs by an analysis of the emitted radiation, but it is a laborious task and subject to many sources of error. However, no contact with the arc is required. Thus, the plasma is not perturbed by the measurements. This attribute is an important advantage which probe techniques do not have.

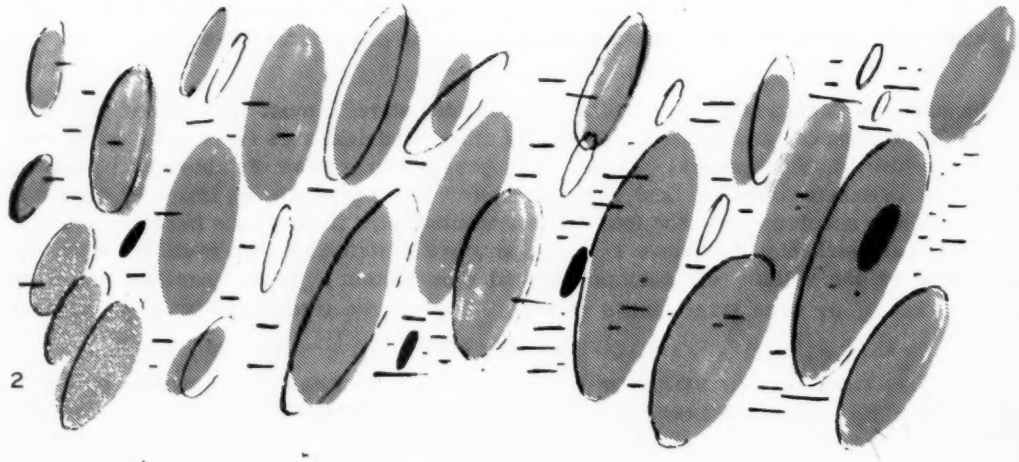
Because the radiation is received in a scrambled state, it must be resolved according to wave length, space, and time. For optically thin cylindrical arcs (most arcs meet these criteria in the visible spectral region), it is possible to achieve the above requirements with a fast calibrated detector and a spectrometer which produces an image of the arc at the exit slit. The resolved radiation intensities are substituted in equations based on quantum and statistical mechanics to arrive at a temperature distribution. However, the equations may depend on the validity of assumptions, and they contain physical quantities which are often not known or have large limits of error. Typical required quantities are transition

probabilities, partition functions, ionization potentials, energy levels, and statistical weights. Because of the above problems, engineers find it difficult to apply conventional techniques to research arcs.

An infrared monochromatic radiation (IMRA) method which does not require a knowledge of the physical quantities discussed in the preceding paragraph was developed to measure the temperature of combustion gases. The spectral emittance and absorptance of the gas are measured. If the gas is in thermal equilibrium, the temperature may be determined from Kirchhoff's radiation law. This law states that the ratio of spectral emittance to the spectral absorptance is equal to the spectral emittance of a black body at the gas temperature. Since the black-body function is known, the temperature is easily determined.

The Thermomechanics Research Laboratory is sponsoring a research program at the Warner and Swasey Company to determine the applicability of the IMRA method to arc plasmas and plasmajets. Dr. R. H. Tourin, who has done considerable work in developing the IMRA technique, is the principal investigator. Preliminary measurements with a plasmajet show that atomic lines of argon, helium, air, and nitrogen may be optically thick (measurable absorptance) in the near infrared. In addition, measured spectral emittances and absorptances were used to calculate IMRA temperatures. Because large temperature gradients exist in the plasmajets, these temperatures correspond to weighted mean values. A comparison of IMRA temperatures for argon with values obtained by measuring the absolute intensity of argon atomic lines show that IMRA temperatures are consistently lower. However, the difference becomes less as the measured absorptance decreases (at shorter wave lengths). Thus, the variation of the IMRA temperature with wave length can be associated with a temperature gradient.

Before the IMRA method can become important in the area of arc plasma diagnostics, a technique must be developed to obtain temperature distributions. Additional work is required before this question can be answered. Hopefully, a series of measurements using different wave lengths or different path lengths will yield the answer. At present, the latter method seems possible if the emission and absorption coefficients in the plasma do not change rapidly with wave length. Although this condition is satisfied by the continuum radiation, it may not be possible to measure the required quantities in this domain. If the above problems are solved, the IMRA method may become an important engineering tool in establishing a theoretical foundation for electric-arc technology.



behavior of LUNAR DUST

DR. JOHN W. SALISBURY
Space Physics Laboratory, AFCRL

Ever since the possibility of a deep surface layer of dust on the moon was first suggested, researchers have debated both its extent and its mechanical properties. The existence of at least a thin layer of fine material produced by micrometeoroid impact is generally accepted. This layer may be locally thick as a result of entrapment of meteoroidal debris by the walls of depressions and, possibly, as a result of downhill electrostatic transport of dust. Thick or thin, however, it appears that sufficient amount of fine material should be present to play a large part in the design criteria of lunar landing and roving vehicles, as well as space suits. For this reason, it is important that we understand the mechanical properties of fine powders in ultrahigh vacuum.

AFCRL is conducting research using a lunar simulation chamber in which the effects of low pressure, radiation, and temperature on the physical properties of probable lunar surface materials are being studied under the direction of Dr. John W. Salisbury. The simulation chamber can attain a pressure of 10^{-10} mm mercury, and has provided the first opportunity for routine experimentation at pressure levels thought to exist at the lunar surface.

Recent experiments, conducted at AFCRL in cooperation with scientists of Arthur D. Little, Inc., have demonstrated for the first time that silicate powders, like metals, adhere to one another in ultrahigh vacuums. In fact, the powder particles will adhere to metals and glass as well as to each other.

Some idea of the strength of this adhesive bond can be obtained from the fact that a plate upon which powder has been sifted at ultrahigh vacuum will retain a layer of powder two or three millimeters thick when turned upside down. The strength of this bond does not diminish in air once it has been formed in vacuum, and is apparently the result of a combination of van der Waals, covalent, and ionic bonds.

These bonds become strong enough to overcome the force of gravity when a very close approach of adjacent particle surfaces is permitted. In air, this close approach of particles is prevented by layers of absorbed water molecules which are removed in the vacuum.

There is good reason to believe that, whatever forces are acting, the bonds between particles on the moon are stronger than those demonstrated so far in the laboratory. Even so, the demonstrated adhesion is sufficiently strong to ensure that the lunar surface layer will have considerable bearing strength. Thus, properly designed vehicles will not sink away into a sea of lunar dust, should one exist. The tendency of dust particles to stick to all metal and glass surfaces will, however, provide an unusual difficulty in the operation of camera lenses, portholes and mirrors.

new instrument for measuring atmospheric humidity

CAPTAIN ROBERT COWNE, USAF, Aerospace Instrumentation Laboratory, AFCRL

A new technique for measuring moisture in the upper atmosphere has been developed for AFCRL by the Minneapolis Honeywell Regulator Company. The technique has been incorporated in a highly sensitive, fast-reacting dew-point hygrometer that overcomes many of the limitations of conventional devices.

The conventional hygrometer, often depending on moisture absorption by some absorbant material, requires as long as five minutes or so to react. More important, conventional hygrometers lose precision in the cold upper atmosphere. With the new AFCRL device, measurements can be made over a range of temperatures with a reaction time of a few seconds.

The sensitivity of the new hygrometer is especially important in moisture-sampling experiments made with balloon-borne equipment.

With the hygrometer, it is possible to sample the moisture content at precise altitude levels during the ascent and descent of the balloon through the atmosphere.

Known as a radiation hygrometer, the instrument consists of a source of alpha particles (Polonium 210), a thermoelectric cooler, radiation counters, and a thermistor for measuring temperature changes. The hygrometer works in the following way: A mirrored or polished surface coated with radioactive Polonium 210 is cooled by the thermoelectric cooler until frost collects on the polished surface. The frosted surface absorbs some of the radiation emanating from the surface. The alpha particle count is decreased and this decrease is read by the particle detector which is separated from the mirror by a one-millimeter air space. When the decreased alpha radiation is detected, the current flow of the thermoelectric cooler is reversed. This action then causes heating of the mirror and the evaporation of the frost. When the radiation count increases again, the current flow is again reversed, the mirror is cooled, frost accumulates, and the alpha particle count is decreased. This cyclic process is extremely rapid so that essentially one temperature, at the particular atmospheric strata being sampled, is maintained. This temperature is constantly measured by the thermistor and is the dew-point (or frost-point) temperature--a basic atmospheric moisture measurement.

The new hygrometer has already been flown successfully in high-altitude balloon experiments and is now being considered for aircraft instrument design. It is well adaptable for use by the Air Weather Service for making humidity measurements by aircraft. Its compact size (1.6 pounds, 4 x 3 x 3 1/2 inches) and ruggedness also make it adaptable for inclusion in high-altitude research probe rockets.

Water vapor is one of the most variable constituents of the atmosphere. AFCRL meteorologists are interested in precise measurements of atmospheric water vapor because of its importance in maintaining the earth's heat balance through the absorption and emission of solar and terrestrial radiation. The precise knowledge of atmospheric water vapor in the atmosphere is important in the development of infrared sensors for various Air Force applications.

DIAGNOSTICS OF HIGH TEMPERATURE *gas streams*

CAPTAIN T. ANDRADA, USAF, Thermomechanics Research Laboratory, ARL

Experimental measurements in high-temperature gas streams, such as produced by high-pressure (above one atmosphere) arc discharges, are limited by a lack of reliable instrumentation and/or proven techniques. The direct and continuous measurements of such basic properties as pressure, voltage gradient, current density, and total energy create complex problems in instrumentation because the temperature level of these gas streams exceeds the melting point of any known material.

The need for more reliable measurement techniques in plasmas has become increasingly important with the advancement of various theories on the heat-transfer process from an arc discharge to a surrounding gaseous flow field. The proposed theories can be verified only with reliable local measurements describing the state of the plasma with respect to the temperature, total energy, pressure, etc. Also, the calculations in all the proposed theories require accurate values of such transport properties as the electrical and thermal conductivities of gases at high temperatures. Presently, for the high-temperature regime, only calculated values of the gas transport properties are available in the literature, and these values may differ by as much as an order of magnitude with various investigators.

The determination of the distribution of the total energy or stagnation enthalpy and stagnation pressure over the cross section of an arc jet is probably the most important measurement for defining the physical state of the effluent gas. These values are a direct measure of the energy transferred from the arc discharge to the surrounding gas stream. From these measurements one can calculate the thermal efficiency of an arc discharge as a gas-heating device. The direct radial distribution of these quantities has until recently received very little attention in most arc-discharge or plasma-jet experiments.

The method used by most investigators to determine the total energy of plasma jets is to calculate the total energy input, subtract all energy losses to the electrodes and the enclosure, and finally arrive at a mean or average total energy in the effluent gas or plasma.

This type of calculation is only valid for obtaining average values of the total energy.

The actual jet issuing from the plasma jet will exhibit strong radial variations of the total energy, temperature, electrical and thermal conductivity, etc. These strong gradient effects are caused by the high-temperature arc core and the cold outer container walls.

Presently, there are three separate investigations being supported by the Thermomechanics Research Laboratory of ARL to study methods for measuring the total energy of high-temperature gas streams. The common features of the different approaches are: (1) direct probing of the gas stream; and (2) miniaturization of the probe (increases spacial resolution, minimizes flow disturbances).

At Princeton University, under the direction of Dr. J. Grey, a method is being investigated using a calorimetric probe. The probe operates on the basis of determining the total energy of an accurately measured gas sample. The probe first ingests a measured sample of gas. The gas sample is then cooled as it passes internally through the probe and the final gas temperature is measured by a conventional thermocouple. The energy transferred from the gas sample to the probe coolant is measured by differential thermocouples.

This technique requires a two-step measurement: first, a measurement with gas flowing through the probe; and secondly, a measurement with no gas flow. The no-flow measurement determines the "tare" or the energy transferred from the gas stream surrounding the outside of the probe.

This probe is also capable of measuring the stagnation pressure and, with additional auxiliary equipment, the gas composition.

At Cornell Aeronautical Laboratories, under the direction of Mr. G. Sterbutzel, another type of calorimetric probe is being investigated. Again a gas sample is ingested into the probe but, instead of relying on heat transfer to the probe to sufficiently cool the gas, a small amount of water is injected directly into the gas sample. By measuring the temperature of the final gas-water mixture and the percent water content, the total energy can be determined. This method does not require a two-step measurement and can operate continuously over long periods of time.

At Thermo-Systems, Inc., under the direction of Dr. H. Fingerson, a dual sensor technique is being investigated. This technique uses two very small (0.006 inch O.D.) internally cooled tubes serving as heat-flux meters. The dual-probe technique permits the calculation of total energy or enthalpy of the gas stream from measured heat-flux data. This calculation is based on the assumption that the enthalpy transfer coefficient to the individual sensors is equal. Due to the small size of the sensors, this technique has a very high frequency response (1000 cycles) and theoretically is capable of rapid radial distribution measurements.

The performance of these various probe techniques will be experimentally verified on one particular plasma jet under identical operating conditions. This comparison test will be performed in the Thermomechanics Research Laboratory at ARL as soon as the various probe concepts are proven feasible in initial tests by the individual investigators.

mathematical descriptions of DYNAMICAL SYSTEMS

MAJ. BERNARD S. MORGAN, Jr., Applied Mathematics Division, AFOSR

If one were to ask engineers active in the systems field what the fundamental mathematical concepts of control theory are, such notions as transfer functions, frequency response, pole-zero patterns in the complex plane, etc. would probably be mentioned most frequently. Yet many recent research papers on control theory hardly even mention these notions. The "fundamental" concept is now the state of the system Instead of transfer functions, one uses vector differential equations; instead of poles and zeros, one talks about eigenvalues of matrices, etc. This new approach has been very successful in solving problems in optimal and computer control, and its potentialities have not been fully exploited.

Is there really a difference between the old and the new? What are the precise relationships between systems described by differential

equations and those described by transfer functions, impulse response functions, etc? Answers to these questions have appeared in a series of papers (1, 2, 3) written by Dr. Rudolph E. Kalman of RIAS under a program of research in the theory of control supported by the Applied Mathematics Division of AFOSR. The highlights of these papers are discussed below.

Using the notions of controllability and observability, it has been proved that all finite-dimensional, linear dynamical systems (i.e., those describable by finitely many ordinary differential equations with time-dependent coefficients) possess a canonical structure consisting of four parts. One part, and only one -- that which is completely controllable and completely observable -- can be identified with the impulse-response function of the system (1).

One can define the state variables of a system described by its impulse response using an abstract procedure, which consists of constructing an "irreducible realization" of that system. For constant systems this can be made completely explicit, and computer algorithms developed. Reference (2) contains a detailed discussion of this and related results.

The impulse-response function identifies the algebraic properties of the system equations, but does not identify stability of the system in the sense of Liapunov without some supplementary assumptions (for instance, constancy or periodicity). Hence the question arises (3) whether or not the stability properties of linear systems can be determined from input-output relations.

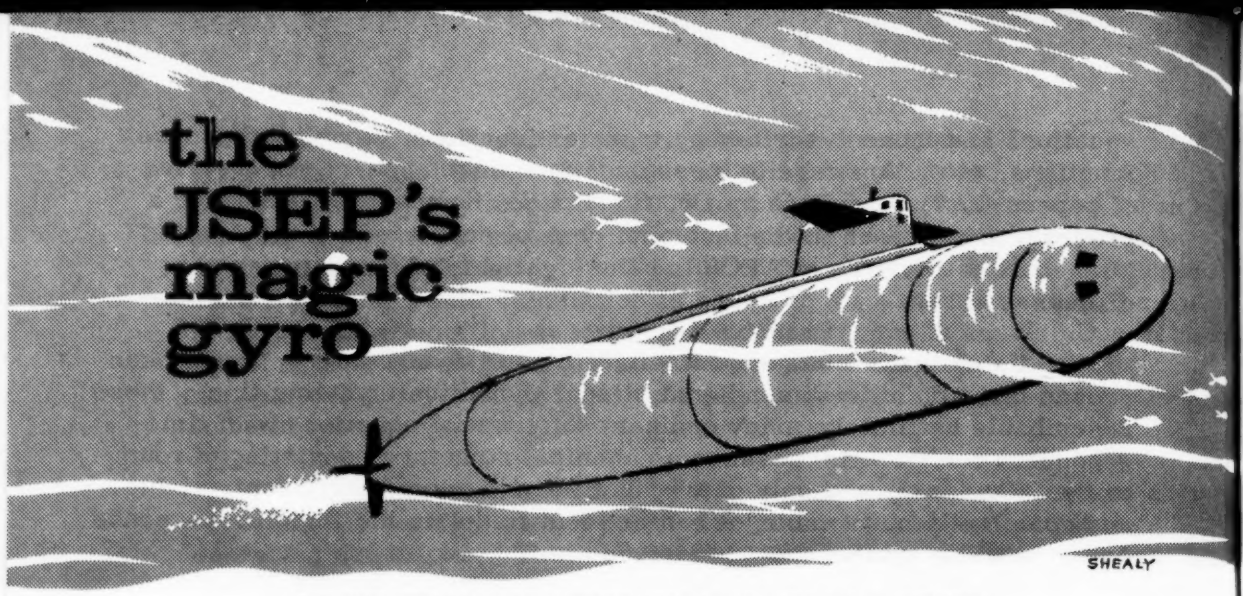
R. E. Kalman

(1) "Canonical Structure of Linear Dynamical Systems," Proc. Nat. Acad. Sci. USAF, 48(1962) 596-600.

(2) "Mathematical Description of Dynamical Systems," J. Control (SIAM), No. 2, April 1963.

(3) "On the Stability of Time-Varying Linear Systems," Trans. IRE Prof. Group on Circuit Theory, CT-9 (1962) 420-422.

the JSEP's magic gyro



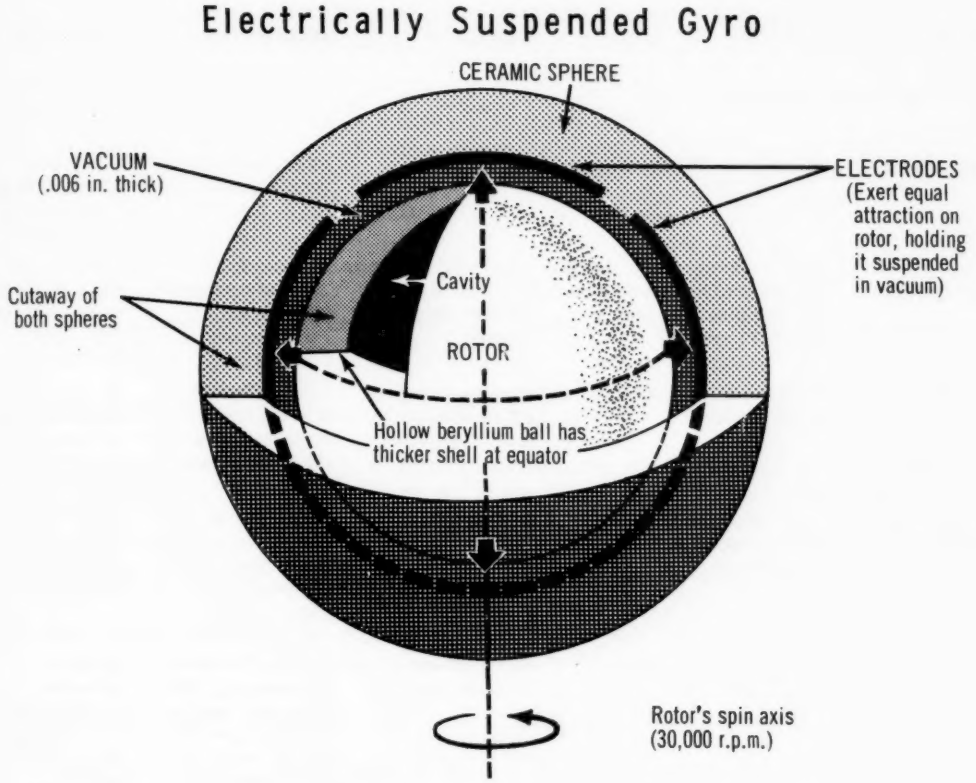
LT COL WILLIAM C. ATHAS, Electronics Division, AFOSR

Spawned from the fertile brain of the University of Illinois' Dr. A. T. Nordiseck (Coordinated Science Laboratory), and guided to fruition under the auspices of the Joint Services Electronics Program (JSEP), the electrically suspended gyro has already earned the nickname "star in a bottle." For, with a "bottled star" on board, the Polaris submarines never need to come near the dangerous surface to check their position by celestial sights.

The electric vacuum gyro, another name for the ESG, is a high-precision, inertial-navigation instrument employing electric fields to create a virtually frictionless bearing. The instrument is a free gyroscope in which a spherical metal rotor is supported by servo-controlled, high-voltage, electric fields emanating from three sets of mutually perpendicular electrodes. The gyro envelope is evacuated to minimize gas drag and to permit higher electric-field intensities without sparking. Magnetic shielding is employed to minimize eddy current drag from stray magnetic fields. During operation the rotor coasts, which it will do for many years after having been initially accelerated by magnetic induction motor coils.

Basically, the gyro consists of a two-inch beryllium ball -- balanced and spherical to within a few millionths of an inch -- suspended by electric fields in an ultrahigh vacuum (about one thousandth of one billionth of atmospheric pressure). The rotor is brought up to its rotation speed of 30,000 RPM by induction coils which produce a spinning electrical field. After a few minutes of initial acceleration,

the power to the coils is turned off, allowing the ball to coast, spinning a few thousandths of an inch from the walls of its chambers. Effectively



isolated from the rest of the universe, the rotor will go on spinning for years, thus providing the gyroscopic equipment necessary for the long space flights and nuclear-submarine extended cruises under the surface of the sea.

The U. S. Navy (BuShips) has recently announced a 1-million-dollar contract with the Minneapolis Honeywell Company to build 28 ESGs. Minneapolis Honeywell also has an Air Force development contract for the gyro. The main difference between the USAF and Navy versions lies in the size of the hollow beryllium sphere -- about a base-ball size for the USAF as compared with the Navy's golfball size. NASA is also interested in the ESG for its APOLLO program. The Navy has already spent more than 20 million dollars to develop the ESG. It is continuing to improve the Polaris submarine's navigation system with its new "monitor" system which will utilize 2 ESGs.

Schedule of Scientific Symposia

DATE	SUBJECT	PLACE	SPONSOR(S)	CONTACT
OAR SPONSORED SYMPOSIA				
25-27 Sep 1963	High-Altitude Plastic Balloons	Boston, Mass.	AFCRL (Aerospace Instrumentation Lab)	Mr. T. Kelly AFCRL (CREB) L. G. Hanscom Field, Bedford, Mass.
8-10 Oct 1963	10th Annual Air Force Science & Engineering Symposium (SECRET)	Air Force Academy, Colorado Springs, Colorado	Office of Aerospace Research and Air Force Systems Command	Maj J. R. Shafer Hq OAR (RRON) Wash. 25, DC
Oct 1963	2nd Bagneres Conference on Lunar Topology	Bagneres-de-Bigorre and Pic-du-Midi Observatory, France	AFCRL (Terrestrial Sciences Lab); U of Manchester (England); Pic-du-Midi Obsv (France)	Mr. M. S. Hunt AFCRL (CRGG) L. G. Hanscom Field, Bedford, Mass.
28 Oct - 1 Nov 1963	International Symposium on Plasma Phenomena & Measurements	San Diego, Calif.	AFOSR (Dir of Engineering Sciences); Inst of Radio Engineers; AEC; NASA	Lt Col G. D. Colchagoff AFOSR (SRE) Wash. 25, DC
11-15 Nov 1963	1st International Conference on Permafrost	Purdue University, Lafayette, Ind.	AFCRL (Terrestrial Sciences Lab); NAS/NRC; NSF; National Research Council of Canada; Navy; Army; Amer Soc of Civil Engineers; U. S. Geological Survey	Mr. G. H. Cabaniss AFCRL (CRGT) L. G. Hanscom Field, Bedford, Mass.
OTHER RDT&E SYMPOSIA OF INTEREST:				
1-4 Sep 1963	International Conference on Oxygen in the Animal Organism	Bedford College London, England	Office of Naval Rsch; Int Union of Biochemists; Int Union of Physiological Sciences	Miss S. Kronheim Office of Naval Rsch Wash. 25, DC
4-7 Sep 1963	3rd International Conference on the Mossbauer Effect	Cornell Univ, Ithaca, NY	ARPA	
5-6 Sep 1963	The Ellipsometer & its use in Measurement of Surfaces & Thin Films	Washington, D. C.	National Bureau of Standards	
23-24 Sep 1963	Aeroelastic and Dynamic Modeling Techniques	Biltmore Hotel, Dayton, Ohio	Aeronautical Systems Div, (AFSC); Aerospace Industries Assoc.	

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